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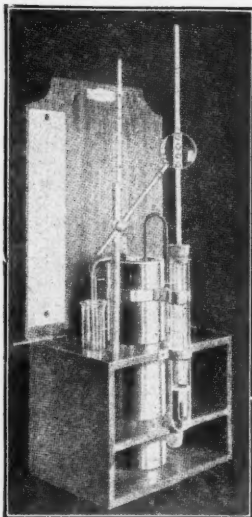Price per volume, net post paid $\begin{cases} \end{cases}$ $5.00, United States, Canada, Mexico, Cuba.
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SOIL SCIENCE

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THE LITMUS METHOD FOR DETECTING THE SOIL REACTION

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INTRODUCTION

Litmus paper is widely used as a qualitative test for acid soils. Barlow (1) has cited the opinions of a number of different authorities as to its value, while Karraker (5) has shown by experiment the great variation in sensitivity which may occur in test paper obtained from different sources. The most systematic study of the behavior of litmus paper in the presence of acids of different strengths is that contributed by Walpole (6) in 1913. He found that blue litmus paper had basicity varying in different papers. This basicity gave the paper a certain "reaction inertia" in dilute solutions of acids. For this reason litmus paper in dilute solutions of highly dissociated acids is incapable of showing the true reaction.

Harris (4) believed that the change in the color of blue litmus paper was due to the selective adsorption of the soil for the base of the blue litmus salt, leaving the red dye on the paper. He supported his belief by citing the fact that in the majority of cases the aqueous extract of acid soils does not redden blue litmus paper. Gillespie and Wise (3) refuting this claim, have shown that the reason the aqueous extract of acid soils does not usually affect blue litmus paper is that such a solution is not buffered strongly enough to overcome the basic nature of the test paper. They show this by comparing the behavior of blue litmus paper in a dilute solution of hydrochloric acid of hydrogen-ion concentration equal to that frequently occurring in the aqueous extract of soils, with that in a well buffered solution of the same hydrogen-ion concentration, for example one of the 0.05 M phthalate series.

THE SENSITIVITY OF BLUE LITMUS PAPER

If azolitmin or litmus paper were as sensitive an indicator as those which have been recently prepared for use in the colorimetric determination of the hydrogen-ion concentration, we should have the ideal indicator for soil work. The range as given by Clark (2) is pH 4.5–8.3. This the writer found to be quite true for the particular paper used in this work. Blue litmus paper in contact with an acid soil is slowly changed in color. The speed and completeness of the change undoubtedly depend both on the degree of acidity (hydrogen-ion concentration) and the buffer or reserve acidity present. In other words, the change would seem to depend upon the total acidity as well as the pH value. To determine which of these seemed to have more influence on the change in color of the litmus paper was the object of this experiment.

The blue litmus paper used was a commercial one, purchased from the Will Corporation, Rochester, N. Y. To determine its usefulness for the particular work, we measured its sensitivity in a dilute, highly dissociated acid

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The color assumed by the litmus paper in each case could be roughly described as pink, slightly pink and very slightly pink with pH values of 4.8–5.2, 5.2–5.8 and 5.8–6.7, respectively. The general conclusion of the experiment would then be that the color of litmus paper in contact with the soil depends on the hydrogen-ion concentration of the soil. Thus this simple test may be used to obtain some approximate idea of the intensity of the acidity.

Frequent reference is made in the literature to the behavior of certain soils toward red litmus paper. In this case the change takes place more slowly and so is less definite. However, certain soils have been described as basic to red litmus paper and the expression needs explanation.

Samples of red litmus paper in this laboratory appear to vary in shade which means that the pH the particular paper is indicating is different. The different papers were judged to vary from pH 4.5 to 6.0. This being the case, it is apparent that theoretically any soil with a pH value greater than that of the paper would cause a change in color toward the basic shade so that a soil may be acid and still cause a change on red litmus paper. Since the usual method for detecting change in litmus paper is by comparison with either a portion of the same strip not in contact with the soil or with another strip of the same paper as a blank, the change in the paper may not necessarily mean a soil is acid. The actual shade of color assumed must be taken into account.

SUMMARY

1. It has been shown that the litmus paper test depends on the hydrogen-ion concentration of the soil.

2. The three shades of color assumed by blue litmus paper in contact with these soils may be roughly described as pink, slightly pink and very slightly pink with pH ranges of 4.8–5.2, 5.2–5.8, and 5.8–6.7, respectively.

3. It is further pointed out that the changing of color of red litmus does not mean a soil is basic unless the proper color (blue) is imparted to the paper.

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SOIL PROFILE STUDIES IN MICHIGAN

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A new concept of soils, in their genetic and geographic relationships, is gaining acceptance among American soil scientists. The fundamental basis and principles underlying this concept originated among Russian workers and have been most comprehensively presented by Glinka (3). In America the principles have been promulgated by Marbut (4) of the United States Bureau of Soils and further the broad scheme has been modified and adjusted for a practicable detailed classification of soils, the principles established, and the criteria stated by him for the recognition of the soil unit.

Soils in their broader relationships are a function of climate. Geology, topography and native vegetation are locally modifying factors. Two important factors of soil formation are the moisture or drainage conditions under which the soils have developed and the time or period through which the soil forming processes have operated. Thus there are two great taxonomic groups: (1) relatively old or mature soils developed under conditions of good drainage; (2) relatively old or mature soils developed under poor drainage. A third group of soils in which the profile is incomplete must be recognized, namely those which are very recent and practically equivalent to geological formations. In such cases, the upper part of the formation or that part which influences plant growth is described in soil terms.

In this scheme of soil classification, the soil profile includes the whole thickness, upon which the soil-forming processes have operated, from the surface down to the parent rock or geologic substratum. The importance of a separation of a profile into its *natural divisions* is emphasized, and the classification is based upon *intrinsic* soil characteristics.

On the basis of this concept of soils and soil classification, field and laboratory studies of soils in Michigan have been undertaken and the preliminary results obtained during the year 1922 are herewith presented.

The primary purpose has been to ascertain chemical and physical facts regarding the soils; to determine whether basic chemical and physical constitutional differences exist between separate members or horizons of the soil

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[1] The field observations and interpretation of soil profiles are largely the work of Veatch and McCool; the hydrogen-ion studies and interpretations of the results are the work of Spurway. Credit for laboratory determinations by others is given in the proper place.

profile and to what extent the visible phenomena in the field can be correlated with laboratory data.

In the geographic studies, the observations in the field seem to justify the division of the state into two soil provinces which we are designating for the present simply as northern and southern. From the nature of things a transition or blending of the soils of the two groups would be expected, but it is impracticable at present, at least, to attempt to draw boundaries for a transitional group or to define a typical profile for such a group. The generalized profiles of the two groups are given below.

PROFILE FOR THE NORTHERN GROUP

(Fairly well to well drained mature soils)

1. Mold
   Humous soil (very thin)
2. Gray or podsolized horizon (3–24 inches)
3. Brown horizon (dark coffee-brown to light leather-color and dull yellow; thickness of 4 inches to 4 feet; horizon of acid concentration)
4. Horizon showing iron oxide coloration, red or yellow; highest clay content; gradation to substratum
5. Substratum.

The thickness of the whole soil layer or complete profile in general is 30 to 48 inches; in the case of the most impervious clays it may not be more than 24 inches, while in the case of some of the most pervious sands it may be as much as 6 feet

PROFILE FOR THE SOUTHERN GROUP

(Well drained mature soils)

1. Mold and humous soil
2. Brownish or yellow horizon
3. Horizon of maximum clay and colloids and maximum intensity of coloring from iron oxide
4. Decrease in iron coloring and decrease in clay content or colloids. Gradational. Small thickness
5. Substratum

Section 3 of this generalized profile for the southern group corresponds to section 4 of the profile for the northern group.

Profile for Sands	*Profile for Heavier Soils*
1. Mold—very thin. (Gray sand, a very thin and inconspicuous horizon in certain situations)	1. Mold and humous soil
2. Brownish humous soil very thin	2. Brown or yellowish horizon
3. Dull yellow sand. Horizon of maximum clay and colloids	3. Horizon of leaching or light colored soil
4. Decrease in intensity of iron oxide coloring. Small thickness	4. Maximum clay, or maximum compactness and plasticity. Gradation to
5. Substratum	5. Substratum high in basic and aluminic rocks and minerals

Horizon no. 3 of the heavier soils is not a true podsolized horizon.

A great number of sub-groups and types may be recognized upon the basis of differences in thickness, texture, structure, consistency and chemical character, but all have the generalized profiles as stated.

The laboratory data have been assembled in tables 1–4.

Discrepancies and inconsistencies appear of which some are easily explainable because of errors in field and laboratory procedure, while others stand as negative and refutive for the present.   But the authors feel justified on the basis of present field and laboratory investigations in drawing the following conclusions and presenting the following theories as a basis for further work.

In the typical northern profile, the surface horizon of virgin soils is obviously one of accumulation, and the higher contents of calcium, magnesium, nitrogen and phosphorus which appear here are believed to be due mainly to organic matter or organic compounds containing these elements.   Beneath this layer of mold soil, the soil forming processes appear to be those of eluviation or removal of the more soluble and finer particles, progressively from the surface downward, as indicated by the relatively higher proportion of silica in the upper part of the profile and increase in calcium and magnesium carbonates with depths.   However, in the northern profile, there appears to have been developed as a subsequent or later phenomenon a brownish or yellowish horizon, one of organic accumulation and of concentration of acids, a horizon much more definitely marked and more strongly developed than in the southern profile.

It is the presence of the acid layer in a definite position in the profile and the strongly marked gray or podsolized horizon which chiefly distinguishes the typical northern from the typical southern profile.   The gray layer appears to have resulted from leaching and it is assumed that organic acids infiltrating from the layer of surface mold have played a strong part in its development. The relative amount of silica in the gray horizon appears to be higher than in the soil horizons below; the content of iron and alumina are fairly consistently higher in the brown horizon than in the gray; the nitrogen content is highest in the surface, lower in the gray horizon, with an upward trend in the curve for the brown horizon, and again a downward trend to the substratum. This condition seems to be true also in a measure for phosphorus.   There is no conclusive evidence of any concentration of calcium and magnesium or other bases in the horizon no. 3, so far as can be determined from the total chemical analysis.

Horizon no. 3 is perhaps the most puzzling feature of the profile in chemical nature and origin.   The brownish or yellowish color is either in large part or entirely organic in nature and organic collodial matter is certainly present. The nature of the organic compounds is not known and their determination would probably be a most complex and intricate undertaking.   The cause for their concentration at a certain position in the profile is equally obscure.   An alkaline (KOH) solution of the brown matter shows iron, alumina, and silica; calcium and magnesium may be present or may be practically absent.   This

TABLE 1

Analyses of northern and transitional soils

LABORATORY NUMBER	HORIZON	SiO₂ per cent	Fe₂O₃ per cent	Al₂O₃ per cent	P₂O₅ per cent	CaO per cent	MgO per cent	Na₂O per cent	K₂O per cent	SO₃ per cent	N per cent	MnO per cent	TiO₂ per cent	H₂O per cent	IGNITION LOSS per cent	CO₂ per cent
3001*	1	91.65	0.96	3.24	0.14	1.06	0.68	0.08	0.83	0.00	0.20					
3002	2	92.55	0.68	2.03	0.12	0.73	0.64	0.00	0.41	0.01	0.05					
3003	3	90.11	1.18	3.73	0.14	0.51	0.58	0.51	1.82	0.00	0.02					
3004	4	94.61	0.68	2.33	0.09	0.45	0.57	0.00	0.52	0.00	0.007					
3005*	1	90.47	1.34	4.75	0.20	0.98	0.65	0.04	1.50	0.06	0.17					
3006	2	92.73	1.22	4.93	0.19	0.61	0.53	0.06	1.05	0.02	0.03					
3007	3	92.98	1.00	4.83	0.17	0.65	0.59	0.02	1.21	0.02	0.02					
3008	4	92.27	0.76	3.77	0.07	0.49	0.62	0.00	1.25	0.00	0.01					
3019*	1	85.50	0.64	1.85	0.09	0.59	0.27	0.03	0.64	0.05	0.28					
3020	2	94.92	0.44	1.15	0.04	0.24	0.28	0.12	0.60	0.02	0.02					
3021	3	90.40	1.40	2.99	0.09	0.32	0.37	0.30	0.92	0.02	0.07					
3022	4	89.88	1.14	3.28	0.09	0.46	0.45	0.31	0.93	0.03	0.05					
3023*	1	74.69	0.98	3.32	0.19	0.63	0.71	0.31	0.37	0.15	0.47					
3024	2	93.34	0.22	2.13	0.07	0.27	0.42	0.67	0.24	0.04	0.01					
3025	3	86.64	0.76	4.48	0.05	0.36	0.36	0.96	1.03	0.06	0.06					
3026	4	89.97	0.80	2.17	0.04	0.28	0.30	0.85	0.99	0.03	0.01					
3053†	2	82.75	1.43	4.70	0.07	1.65	1.55	1.38	2.76	0.19	0.04	0.03	0.63	0.55	2.42	0.20
3054	3	64.85	4.90	9.38	0.07	2.30	2.98	1.63	3.55	0.15	0.05	0.12	0.40	2.60	6.85	0.22
3055	4	55.41	5.45	10.33	0.15	4.50	4.60	1.06	3.70	0.21	0.06	0.16	0.50	3.04	10.82	3.83
3056	Sub	40.04	3.95	7.11	0.12	15.73	6.50	1.64	2.65	0.17	0.04	0.10	0.62	2.03	18.29	15.23
3035*	1	98.05	0.72	2.93	0.07	0.81	0.34	0.28	0.72	0.06	0.13					
3036	2	92.11	0.56	1.34	0.04	0.50	0.30	0.00	1.15	0.03	0.04					
3037	3	91.00	1.00	3.91	0.10	0.67	0.54	0.00	1.02	0.03	0.01					
3038	4	96.38	0.82	3.32	0.05	0.70	0.53	0.04	1.04	0.05	0.00					

Sample	Layer															
3039*	1	68.04	1.40	4.76	0.25	2.24	0.45	0.66	1.43	0.17	0.65					
3040	2	86.96	0.84	3.57	0.02	0.62	0.32	0.87	1.28	0.05	0.04					
3041	3	86.18	1.48	4.69	0.04	0.69	0.42	0.64	1.12	0.04	0.04					
3042	4	69.59	2.16	6.37	0.09	6.22	0.62	0.57	1.13	0.06	0.02					
3044*	1	84.44	0.28	0.65	0.08	0.52	0.52	0.02	0.25	0.07	0.30					
3045	2	.....	0.16	0.16	0.02	0.29	0.33	0.00	0.21	0.04	0.03					
3046	3	80.12	0.73	2.95	0.04	0.49	0.30	0.47	0.59	0.08	0.11					
3047	4	97.53	0.73	2.15	0.04	0.53	0.28	0.37	0.57	0.04	0.01					
3048*	2	92.61	0.66	2.47	0.08	0.35	0.29	0.01	0.92	0.05	0.03					
3049	3	88.88	0.96	3.93	0.13	0.41	0.44	0.03	1.08	0.03	0.02					
3050	4	92.01	0.95	3.42	0.07	0.42	0.30	0.12	1.13	0.03	0.00					
3051	Sub	93.01	0.84	2.99	0.07	0.41	0.39	0.05	1.17	0.03	0.00					
3057*	1	88.15	0.80	3.03	0.12	0.49	0.38	.....	0.80	0.07	0.10					
3058	2	92.99	0.82	2.96	0.05	0.34	0.38	.....	0.92	0.03	0.04					
3059	3	91.97	0.91	3.47	0.10	0.38	0.40	.....	1.23	0.03	0.03					
3060	4	96.22	0.80	3.29	0.09	0.42	0.35	.....	1.08	0.03	0.00					
3062†	1	48.40	1.00	0.59	0.09	1.75	1.25	0.68	0.99	0.34	0.45	0.07	0.20	3.72	41.50	0.11
3063	2	87.85	1.18	1.44	0.06	1.33	1.23	0.88	1.72	0.12	0.07	0.04	0.45	0.75	3.48	0.10
3064	3	80.63	1.88	4.03	0.09	1.75	1.80	1.24	2.14	0.07	0.06	0.03	0.50	1.28	4.15	0.08
3065	4	84.12	1.95	3.80	0.05	1.18	1.60	1.13	1.97	0.13	0.03	0.07	0.30	0.83	2.57	0.06
3066	Sub	72.27	1.85	3.24	0.07	5.93	4.03	1.07	1.72	0.08	0.02	0.08	0.22	0.68	8.21	6.05

* Analysis by P. S. Brundage, Michigan Agricultural College.
† Analysis by O. B. Winter, Michigan Agricultural Experiment Station.

horizon in nature varies from 2 or 3 inches in thickness to as much as 4 feet, from an obscure yellow coloration to very dark brown; it appears at 6–30 inches from the surface. Where the sands prevail there is the most marked development in general, where the highest aluminic conditions are at present there is the least thickness and most obscure development.

TABLE 2

Analyses of southern soils

LABORATORY NUMBER	HORIZON	SiO₂	Fe₂O₃	Al₂O₃	P₂O₅	CaO	MgO	Na₂O	K₂O	SO₃	N	MnO	TiO₂	H₂O	IGNITION LOSS	CO₂
		per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
3015	1	88.47	0.43	3.23	0.07	0.41	0.28	0.04	0.93	0.07	0.17					
3016	2	94.50	0.52	2.57	0.04	0.41	0.26	0.05	0.90	0.03	0.03					
3017	3	93.15	0.56	3.30	0.06	0.41	0.30	0.44	1.02	0.02	0.03					
3018	4	92.69	0.60	3.19	0.04	0.49	0.30	0.32	1.10	0.03	0.00					
3027*	1	86.38	0.76	1.65	0.16	0.34	0.29	0.43	1.08	0.06	0.24					
3028	2	89.28	1.22	3.60	0.12	0.44	0.72	0.65	0.37	0.05	0.05					
3029	3	91.92	1.02	3.72	0.06	0.49	0.45	0.57	0.41	0.06	0.02					
3030	4	92.66	0.96	3.71	0.08	0.46	0.49	0.78	0.42	0.06	0.00					
3031*	1	78.51	2.10	7.04	0.34	1.08	0.58	0.57	1.38	0.11	0.27					
3032	2	80.78	2.54	6.98	0.15	0.76	0.64	0.42	1.67	0.06	0.04					
3033	3	77.91	3.37	8.58	0.10	0.91	0.89	0.59	1.47	0.05	0.03					
3034	4	76.39	6.17	8.02	0.15	0.98	1.03	0.64	1.27	0.04	0.01					
3067*	1	74.60	2.10	1.85	0.22	1.73	1.95	1.30	1.82	0.62	0.21	0.15	0.28	1.98	10.33	1.87
3068	2	77.40	2.80	5.18	0.12	1.85	2.03	1.22	2.00	0.08	0.08	0.12	0.48	1.30	5.16	0.32
3069	3	76.85	3.65	4.48	0.09	1.78	2.10	1.12	1.97	0.05	0.05	0.31	0.53	1.82	5.70	0.07
3070	4	87.01	2.50	2.08	0.05	1.85	1.43	1.14	1.54	0.07	0.02	0.08	0.45	0.38	1.89	0.15
3071†	1	68.77	2.25	1.89	0.14	2.20	2.40	0.99	2.14	0.23	0.40	0.25	0.57	2.74	15.38	0.27
3072	2	77.20	3.10	3.60	0.08	1.85	1.90	1.11	2.39	0.24	0.11	0.15	0.40	1.40	6.40	0.19
3073	3	76.08	3.80	7.04	0.06	1.13	1.70	1.08	2.64	0.18	0.05	0.22	0.60	1.35	4.53	0.18
3074	4	70.14	3.70	10.91	0.07	1.68	2.35	0.94	2.58	0.14	0.04	0.14	0.40	1.61	5.31	0.37
3075	Sub	56.13	3.80	6.83	0.08	9.60	5.05	0.97	2.61	0.24	0.03	0.15	0.54	1.04	12.71	10.45

* Analysis by P. S. Brundage, Michigan Agricultural College.
† Analysis by O. B. Winter, Michigan Agricultural Experiment Station.

If it is true in general, as it appears to be, that the more calcareous and more clayey soils exhibit the least marked development of horizon no. 3, a possible explanation is that a larger proportion of the humic acid is combined with calcium and magnesium to form the less soluble humates, whereas with the sandier and less basic soils there is not sufficient calcium and magnesium to hold the organic acids at the surface and these filtrate downward and at certain points in the profile are precipitated or flocculated. Sodium, potas-

TABLE 3
Description of soils in northern and transitional group

LABORATORY NUMBER	HORIZON	REACTION	LIME REQUIREMENT	UNFREE WATER† (DILATOMETER)	HEAT OF WETTING†	SOIL DESCRIPTION
		pH	lbs.*		cal.‡	
3001	1	6.12	960	2.3	125.40	Transitional soil, deep dry sand. Horizon
3002	2	6.71	120	1.3	43.45	3 not markedly developed as to the
3003	3	6.51	320	1.4	52.75	brown organic matter. Horizon 4 in-
3004	4	5.83	240	0.5	13.19	cludes a part of the substratum. Virgin
						soil, but in old cut-over forest
3005	1	6.73	600	2.2	94.25	Transitional soil, sand. Brown horizon,
3006	2	5.93	400	0.9	50.62	no. 3, obscurely developed, substratum
3007	3	5.93	400	0.7	37.58	clay. Sample from a depth of 5 feet.
3008	4	5.92	280	1.1	24.17	Virgin soil, but in old cut-over forest
3009	Sub	6.71	600	...	......	
3019	1	5.60	1600	3.3	153.03	Typical northern profile, well drained sand;
3020	2	4.58	600	0.8	20.67	horizon 2 is 10–12 inches in thickness;
3021	3	4.65	3200	1.5	69.80	horizon 3, brown color from organic mat-
3022	4	4.94	2240	...	.....	ter, strongly marked
3022½	Sub	5.63	600	...	......	
3023	1	5.06	5200	4.4	155.35	Marked development of brown horizon,
3024	2	4.89	560	0.7	16.82	no. 3. Sand soil; poor drainage
3025	3	4.48	8040	1.4	140.08	
3026	4	4.82	1220	0.8	28.87	
3026‡	Sub	5.28	400	...	......	
3039	1	7.46	....			Loam soil; typical northern profile; brown
3040	2	6.41	360			horizon no. 3, is 6 to 8 inches from the
3041	3	5.14	1560			surface. No. 4 and substratum, previous,
3042	4	7.47	....			reddish, calcareous clay
3043	Sub	8.25	....			
3044	1	4.31	7000	4.4	186.79	Sandy soil, poor drainage; virgin unburned
3045	2	4.28	320	0.5	14.97	accumulation or organic matter at surface.
3046	3	4.28	8000	2.4	159.96	Marked development of brown horizon
3047	4	4.99	720	0.1	16.55	
3048	2	5.29	640	0.7	16.23	Sandy soil and sand substratum; dry and
3049	3	5.12	960	1.0	37.84	well drained. Obscure development of
3050	4	5.28	280	0.5	7.64	brown horizon
3051	Sub	5.17	200	0.5	7.47	
3057	1	5.43	1520	1.8	62.62	Dry sandy soil. Horizon 2, only 2–3 inches
3058	2	4.77	1240	1.3	38.54	in thickness, not typical podsol, contains
3059	3	4.85	1240	1.1	40.55	a considerable percentage of organic
3060	4	4.99	520	1.1	17.90	matter
3061	Sub	5.28	400	0.4	10.37	

* Calcium required to bring two million pounds of soil to the neutral point.

† Dilatometer and heat of wetting determinations made by A. G. Weidemann.

‡ Calories of heat produced per 50 gm. of soil.

TABLE 3—*Continued*

LABORA-TORY NUMBER	HORI-ZON	REAC-TION	LIME RE-QUIRE-MENT	UNFREE WATER† (DILA-TOMETER)	HEAT OF WETTING†	SOIL DESCRIPTION
		pH	*lbs.*		*cal.‡*	
3035	1	5.95	920	2.2	87.18	Transitional soil, well drained, loose sand
3036	2	4.82	800	1.1	29.58	throughout; brown horizon, no. 3 poorly
3037	3	4.92	1000	1.1	29.33	developed. Virgin soil, cut-over forest
3038	4	5.00	320	0.7	18.67	
3076	1	6.07			265.30	Fairly typical northern soil; sandy loam,
3077	2	5.36			23.56	well developed brown horizon, 6–8 in. in
3078	3	5.31			57.20	thickness, gravelly substratum alkaline
3079	4	5.46			11.34	
3081	1	7.51			609.80	Virgin soil, horizon 1, first 2 inches of forest
3082	2	6.44			40.79	mold; well marked brown horizon 24
3083	3	5.28			98.63	inches in thickness; substratum at 48
3084	Sub	7.13			12.49	inches calcareous sand
3085	1	7.49			781.10	Very high percentage of organic matter in
3086	2	6.95			39.15	horizon 1. Well marked brown horizon 3,
3087	3	5.88			53.54	beginning at 12 inches; substratum, sand,
3088	Sub	7.73			41.35	gravel clay mixture, pervious calcareous
3089	1	7.22			571.90	Light sandy loam, well drained; horizon 2
3090	2	6.68			89.69	contains a high percentage of organic
3091	3	5.73			45.22	matter than is typical; fairly well devel-
3092	Sub	7.17			13.77	oped horizon. Sand and gravel, pervious
						substratum
3094	1	5.11			.....	Dry sand, horizons 2 and 3 both poorly
3094½	2	4.94			33.85	marked in the profile. Loose quartz sand
3095	3	4.94			27.66	substratum
3096	4	5.34			23.00	
3097	Sub	5.70			9.20	
3097½	1	4.56			492.20	Dry sand; horizons 2 and 3 well marked
3098	2	5.66			10.37	and 10 and 12 inches in thickness respec-
3099	3	5.02			40.45	tively. Sample 30101 represents sub-
30100	4	5.39			16.72	stratum at 12 feet
30101	Sub	5..65			5.40	
30102	1	4.51			198.56	Transitional soil, well drained loose sand.
30103	2	4.26			46.67	Horizons 2 and 3 obscurely marked in the
30104	3	4.89			32.37	profile
30105	4	5.48			11.26	

TABLE 3— *Continued*

LABORA-TORY NUMBER	HORI-ZON	REAC-TION	LIME RE-QUIRE-MENT	UNFREE WATER† (DILA-TOMETER)	HEAT OF WETTING†	SOIL DESCRIPTION
		pH	*lbs.**		*cal.*‡	
30106	1	7.27			.....	Old dune sand; brown horizon 3 con-
30107	2	5.43			4.56	spicuously marked, reaching a thickness
30108	3	5.41			40.02	of 4 feet. Sample 30109 from a depth
30109	Sub	7.57			10.01	of 6 ft.
30110	1	4.78			.....	Sand soil, poor drainage; horizon 3 a dark
30111	2	4.65			18.15	color, and slightly cemented
30112	3	4.60			121.72	
30113	4	5.31			34.12	

sium and nitrogen should show an increase in the third horizon.   The chemical analyses afford a measure of evidence to support the above theory.

As the pH data show (5) considerable differences exist in the reaction of the various horizons of the soil profiles.   The surface horizon may be acid or alkaline but the second and third horizon was found to be acid even in the limestone soils.   The degree of acidity becomes less as the substratum or parent material is approached, or the reaction may be alkaline if limestone is encountered in quantities sufficient to exert its effects on the fine soil material.

It is evident from these results that the reaction of the profiles, or of the separate horizons, is not a determinative factor in the formation of these soil profiles, and that podsolization may take place in acid or alkaline oils; how-ever, there appears to be an acid limit, which is in the region of pH 4.3.   The reaction of these horizons is considered to be the result of chemical actions accompanying soil formation processes, and not a contributing cause of these processes.

As to the nature of the soil compounds causing the acid reaction of the several horizons, little is known at present.   The specific cause of the reaction itself is undoubtedly the ratio between concentrations of hydroxyl and hy-drogen ions in the soil solutions.   In case of the typical northern group of podsolized soils there is a concentration of an acid substance or substances in the third or brown horizons as shown by their high lime requirements; but in the case of the transitional and southern groups, we have no positive data to show, whether the increased acidity of the second or third horizons is due to accu-mulation of acids or removal of bases; both factors may be operating with varying degrees of intensity.   The possibility of a change in chemical com-position affecting the solubility of the chemical components of these horizons must also be considered.   Whatever may be said regarding the causes of the reaction of soils, we maintain that a specific reaction is the resultant of all its contributing causes, and as these causes vary in effect the soil reaction varies accordingly.

TABLE 4

Description of soils in southern group

LABORA-TORY NUMBER	HORI-ZON	REAC-TION	LIME RE-QUIRE-MENT	UNFREE WATER (DILATOM-ETER)	HEAT OF WETTING	SOIL DESCRIPTION
		pH	*lbs.*		*cal.*	
3015	1	5.43	1840	1.8	75.67	Loose, dry sand, loose sand substratum,
3016	2	4.87	760	0.5	27.66	surface, virgin, unburned forest mold
3017	3	4.87	800	0.9	19.15	
3018	4	6.10	120	0.6	4.50	
3027	1	4.82	2320	2.7	109.32	Well drained sand; mature or old soil.
3028	2	4.43	1560	1.4	49.96	Horizon 3 in the sample includes a greater
3029	3	5.33	720	0.8	20.53	thickness than properly belongs to it.
3030	Sub	4.94	440	0.8	17.29	Substratum a loose incoherent sand
3031	1	6.32	1160		179.42	Loam soil, well drained. Horizons 3 and 4
3032	2	5.43	1160		65.52	friable reddish clayey horizons, with
3033	3	5.19	1320		121.94	maximum clay in horizon 3. Substratum
3034	4	5.33	1120		123.91	coarse, contains horizon limestone and
3034½	Sub	....	....		......	basic rocks
30118	1	5.55			129.52	Old, well drained sand soil. Horizon 3
30119	2	5.12			59.77	slightly loamy, barely coherent. Sand
30120	3	5.63			36.63	and gravel substratum below 4 feet
30121	4	5.39			23.26	
30122	1	6.05			133.53	Sandy loam soil, no. 3, lightest color
30123	2	5.41			32.35	and apparently maximum leaching. No.
30124	3	5.31			24.07	4, strongly cohesive reddish sandy clay,
30125	4	5.53			90.36	18 inches in thickness. Substratum,
30126	5	7.39			18.35	gravelly, sandy, calcareous
3067	1	4.23			153.64	Dark colored loam, high content of humus
3068	2				112.55	in surface soil; horizon 3 compact sandy
3069	3				135.39	clay; horizon 4 at 36 to 48 inches, sand
3070	4				39.10	and gravelly, includes part of substratum
3071	1				235.38	Well drained heavy soil; horizon 2 at 4 to
3072	2				106.31	8 inches a gray floury silt; horizon 3
3073	3				114.88	mottled plastic clay; horizon 4 pale
3074	4				142.98	yellowish clay; substratum, clay from a
3075	Sub				104.46	a depth of 4 ft.

The practical significance of these reaction results should not be overlooked. The degree of reaction or chemical composition of the surface horizon may be no indication of the reaction or composition of the underlying horizons; also they may not indicate adaptation to plant growth.   A plant may extend its roots into one or more horizons, and thus grow in soils varying in reaction from akaline to acid, in soils with various degrees of acidity, or in soils varying greatly

in chemical composition. It is evident in this connection that the soil profile as a whole is the unit to be considered in questions of plant adaptation or soil management. In scientific investigations pertaining to soils, it is also evident that soils should be sampled with respect to soil profiles and their horizons and not on the basis of linear depths alone.

In discussing the lime requirement data, consideration should be given to the fact that they refer to horizons of virgin soil profiles that vary greatly in thickness and represent effects of extreme conditions of soil formation; hence these results can not consistently be compared to the lime requirements of surface cultivated soils. In case of the southern and transitional groups, no marked increase in lime requirement is shown by the "no. 3" horizons over the others and, in general, the lime requirement diminishes in magnitude with depths. In the typical northern profiles, however, a marked accumulation of acids is shown in the third horizons and also in the surface humus layers except in case of the soil no. 3039, in which there is clearly an influence by limestone.

The heat of wetting (1) determinations show fairly consistent differences for the different horizons recognized in the field. It is believed that these determinations reflect differences in the amounts of organic and colloidal matter present, of active matter as opposed to the more inert crystalloid matter, and of unfree water (2). The heat of wetting is highest for the surface horizon, decreases for horizon no. 2, increases for horizon no. 3, and thence shows a uniform decrease with depth to the substratum.

In the typical southern profile, the surface horizon of the virgin soil is one of accumulation and accretion as in the northern profile, but beneath this the process seems to be one of eluviation. The progressive increase in calcium and magnesium carbonates with depth and the sandier and less clayey nature of horizon no. 2 afford evidence of this. There is no conclusive evidence so far either in the field observations or in the laboratory determinations of a horizon of concentration or accumulation formed either through precipitation of downward moving soluble matter or through mechanical translocation. No one horizon maintains consistently a maximum or minimum degree of acidity or alkalinity, but in the case of the heavier soils, where the layer of clay or maximum colloid content reaches its most marked development, there is a suggestion that the highest degree of acidity may prevail in a leached sub-horizon resting directly upon the clay layer.

The nitrogen shows a consistent decrease from the surface downward, that is, there is no consistent rise in any horizon beneath the humous soil. The iron and alumina are highest in horizon 3 and 4 in the profile of the heavier soils. On the assumption that the soil compounds of these elements are the more acid and more insoluble, they would persist longer under the action of leaching processes. The theory is offered that as no. 3, or the layer of maximum clay and colloids, is decreasing in thickness and undergoing transformation through removal of its constituents, no. 4 and the upper part of the

substratum are concurrently changing to the nature of no. 3, through the action of soil weathering or soil forming processes. In the mature soil, possibly, an equilibrium has been established. The leaching process in soil formation becomes more marked in proceding southward in the United States, as the mean temperature becomes higher and the summer rainfall greater, until it reaches an extreme in Florida.

The heat of wetting is high in the surface horizon, evidently because the accumulation of organic matter, and highest in horizon no. 3, where it apparently bears a relation to the maximum clay or active inorganic colloidal matter.

The laboratory investigations as far as they have progressed point to fairly consistent physical and chemical differences for the separate horizons as they have been interpreted in field studies. The authors believe that such profile studies as here outlined constitute a step forward in soil science. The profile study of soils will revolutionize the methods of sampling soil and as pointed out by Marbut (2) give a new meaning and value to analytical work. Further, it compels a new evaluation of soil in ecologic studies, since the soil assumes added importance as a factor when the chemical and physical differences of the separate horizons are studied in relation to root development. It places soil study on a natural basis and in fact lays the foundation of a new science which we might name, *podology*.

<h2 style="text-align:center">REFERENCES</h2>

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COMPARATIVE EFFECTS OF MURIATE AND SULFATE OF POTASH ON THE SOIL IN A LONG CONTINUED FERTILIZER EXPERIMENT[1]

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Field B of the Massachusetts Agricultural Experiment Station has been used since 1893 for comparing the effects of muriate of potash and sulfate of potash on crop production. The field contains 10 plots of $\frac{1}{8}$ acre each, which are numbered from 11 to 20 inclusive. Those with odd numbers have received muriate of potash and those with even numbers, the sulfate. Descriptions of the experiments and results are given in the annual report of this station in the annual reports for the years 1918 to 1923.

During the first 7 years, each potash salt was applied annually at the rate of 400 lbs. per acre; but since 1900, the quantity has been 250 lbs. Nitrogen and phosphoric acid have been supplied in ground bone at the rate of 600 lbs. per acre annually. In addition to the potash salts and bone, all the plots have received applications of lime; but the quantities and time of application have varied with different pairs.

The plots have been compared in pairs, 11 with 12, 13 with 14, 15 with 16, 17 with 18, and 19 with 20. Two pairs of plots have seldom been planted with the same crop in one year and every pair has borne a variety of crops during the experiment. The two salts have differed some in their effects on crops. Sulfate of potash has proved superior in production with more crops than muriate. A difference in the tints of the foliage upon a pair of plots was sometimes striking. Raspberries showed more winter injury on their muriate plot, and on one occasion an early frost severely injured squash vines on another muriate plot while on the adjoining sulfate plot the leaves were scarcely touched.

On account of the long continued use of the two distinct salts on these plots, Director Brooks deemed it important to know whether any cumulative effects had developed in the composition of the soil, which would distinguish one series from the other. Three pairs of plots were selected, 11 and 12, 15 and 16, 17 and 18, and samples of the soils were secured in November, 1915, after 22 successive applications of the fertilizers. Each plot was sampled by making numerous borings with an auger to the depth of seven inches.

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When air-dry, the soil was sifted through a standard sieve with 1-mm. holes, and the fine material used for chemical analysis. The soil has been classified as Merrimac sandy loam (5, p. 158).

Not much information was expected from an analysis by the common method of solution with HCl of sp. gr. 1.115, but two composite samples prepared respectively from the soils of the muriate plots, 11, 15 and 17, and sulfate plots, 12, 16 and 18, were analyzed with the results shown in table 1. The analytical work was executed by Mr. C. L. Beals.

The results are closely parallel and show the uniformity of the two series in composition. The widest proportional difference is with sodium oxide, but it should be borne in mind that this determination is the most difficult one of the series to keep free from errors, so no especial significance can be attached to the difference.

TABLE 1

Composition of soils of field B

CONSTITUENTS	PLOTS 11, 15, 17 TREATED WITH MURIATE	PLOTS 12, 16, 18 TREATED WITH SULFATE
	per cent	*per cent*
Silica and insoluble matter	85.31	84.86
Potassium oxide	0.14	0.13
Sodium oxide	0.21	0.15
Calcium oxide	0.50	0.49
Magnesium oxide	0.69	0.72
Manganese oxide	0.09	0.10
Iron oxide	2.58	2.49
Aluminum oxide	4.14	4.19
Phosphoric anhydride	0.12	0.12
Sulfuric anhydride	0.08	0.08
Volatile matter	5.35	5.65

The samples from the individual plots were next analyzed by methods which might show whether the important bases, potassium, calcium and magnesium, differed in the solubility of their compounds on the two series. Standard fusion methods were used to determine total K_2O, CaO and MgO, while 0.2 N HNO_3 and distilled water were each used to determine their soluble forms, as both solvents have been often used in soil-studies. Sufficient soil and solvent were used to permit concentration of the solution and gravimetric determination of each constituent.

The only noticeable differences between the two series of soils, analyzed plot by plot, were that total lime and available lime were uniformly a trifle higher in the muriate soils than in the sulfate soils. The results of the analyses are averaged in the table. Potash was practically alike in both soils, and the amount soluble in 0.2 N acid was so small that no determination of its solubility in water was attempted. The magnesia results were also closely alike.

The quantities of lime that these plots had received were not uniform in amount or year of application.   Plots 11 and 12 received 3000 lbs. hydrated lime per acre in 1910; plots 15 and 16 received 2000 lbs. per acre in 1905 and again in 1915; plots 17 and 18 received only 2000 lbs. per acre in 1915.   The water-soluble lime was closely alike in all the soils, and this was also shown later by the reaction of the solutions.

The magnesia results by each method are practically alike on the two series and are small in quantity by the two solvents.

In spite of the well known difference in solubility of calcium chloride and calcium sulfate, which should be formed by the action of the respective potash fertilizers on the lime in the soil, the lime appears to have been removed less by the muriate than by the sulfate of potash treatment.

When the solubility effect of rain-water is considered, there is reason to expect both compounds of calcium to be completely removed annually, insofar as they are produced by the action of the potash salts.   The less soluble $CaSO_4$ dissolves in water at 18° at the rate of 2.016 parts in 1000 (2).   An

TABLE 2

Potash, lime and magnesia in the soils of field B by different methods, expressed in percentage of dry soil

	K_2O		CaO		MgO	
	Muriate soil	Sulfate soil	Muriate soil	Sulfate soil	Muriate soil	Sulfate soil
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Total by fusion..................	1.84	1.81	1.91	1.68	1.06	1.09
Available by 0.2 N HNO₃.........	0.012	0.011	0.175	0.162	0.028	0.037
Soluble in water...............			0.0105	0.0106	0.0047	0.0050

acre-inch of water should weigh 226,875 pounds and be capable of dissolving over 450 pounds of the substance.   The application of 250 lbs. of sulfate of potash cannot produce more than 195 lbs. calcium sulfate.   Therefore, a season's rainfall and percolation should completely remove the calcium compounds formed by the action of the respective potash fertilizers applied in the spring, whether as sulfate or as chloride.

Further study of the comparative effects on the lime of the soil was made by determining the lime requirements of the different plots.   It has already been mentioned that each pair of plots had received a different amount of lime from either of the other pairs.   The determinations were made by Mr. Beals and both the Veitch (4) and the Hopkins (1, p. 20) methods were used.

Plots 11 and 12 showed like results by both methods.   Plots 15 and 16 differed somewhat, and it was noted when the samples were prepared by sifting that the one from 16 contained visible particles of lime.   This pair of plots was bearing raspberries, which had interfered with thorough surface tillage.   The second application of lime was made in the spring of the year

in which the samples were taken. The lower lime requirement on plot 16 is attributed to possible difference in tillage rather than to the lesser effect of sulfate of potash. Plots 17 and 18 differed a little, but the two methods do not agree in the relative positions of the two.

Mr. C. P. Jones determined the residual carbonate of lime in four of the samples, using MacIntire's method (3, p. 83–97) for determining CO_2. Plot 11 contained more carbonate than 12, while plot 15 contained less than 16. Therefore no deduction can be drawn from these studies of the lime requirements or residual carbonates that would favor either potash salt.

The results of these different methods of soil analysis show no evidence of cumulative effects or residues due to the continuous use for 22 years of two distinctly different potash salts, with the possible exception of the slightly greater retention of calcium on the muriate plots.

TABLE 3

Lime requirement of soils of field B, expressed in parts per million of dry soil

	TREATED WITH MURIATE			TREATED WITH SULFATE		
	Plot 11	Plot 15	Plot 17	Plot 12	Plot 16	Plot 18
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Hopkins method...............	50.0	62.5	50.0	50.0	37.5	75.0
Veitch method.................	5712.0	5712.0	6120.0	5712.0	5314.0	5712.0

TABLE 4

Residual calcium carbonate in soils of field B, expressed in pounds per acre foot

TREATED WITH MURIATE		TREATED WITH SULFATE	
Plot 11	Plot 15	Plot 12	Plot 16
lbs.	lbs.	lbs.	lbs.
1566	1236	1170	1688

Having found but little evidence of cumulative differences in the respective effects of long continued yearly applications of muriate and sulfate of potash, some studies have been made to ascertain possible temporary differences that may arise following their application in the spring.

In this connection, a percolation experiment by the author assisted by Mr. R. W. Ruprecht, will be presented. The experiment was made in connection with other soil studies but is of use here. Samples of soil were obtained in July, 1914, from plots 11 and 12, on which, at the time, a crop of alfalfa was growing. The samples were obtained by driving cylinders of galvanized iron, 3 inches in diameter, vertically downward into the soil to a depth of 8 inches. The cylinders and contents were removed intact and taken to the laboratory. A perforated cap was placed over the bottom of each cylinder, which was then set in a vertical position over a beaker. Water

was applied to the top of the cylinder from time to time and allowed to percolate through into the beaker.   The object of the experiment was to learn the nature of the substances in the drainage-water from these two plots.

One pair of cylinders was subjected to two percolations of 500 cc. each. A second pair underwent six percolations of 500 cc. each.   A third pair was first saturated with water and allowed to stand 24 hours before adding more, after which it was subjected to five percolations of 500 cc. each.   Each 500 cc.

TABLE 5

Composition of percolates from soils of field B, expressed in parts per million of solution

	TOTAL SOLIDS IN SUCCESSIVE PERCOLATES					
	1	2	3	4	5	6
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Experiment 1 (air-dry soil)						
Muriate soil..................	526	152				
Sulfate soil...................	270	172				
Experiment 2 (air-dry soil)						
Muriate soil..................	442	114	100	92	92	98
Sulfate soil...................	246	174	124	38	80	80
Experiment 3 (core first saturated for 24 hours)						
Muriate soil..................	138	80	100	72	60	
Sulfate soil...................	320	138	110	104	62	

	AVERAGE COMPOSITION OF ALL PERCOLATES				
	Total solids	CaO	Cl	SO₃	Na₂O
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Muriate soil........................	159	26	18	18	20
Sulfate soil.........................	151	37	3	40	20

of water on the surface of the cylinder was equal to a depth of 4.4 inches and therefore was equal to that depth of rainfall.

Total solids were determined in each 500 cc. of percolate.   Determinations of CaO, Cl, SO₃ and Na₂O were made in the combined percolates from the respective plots, after concentration to a small volume.

The total solids in the percolates decreased sharply after the first portion had passed, which is the usual result in such experiments.   In experiment 3, the increased solubility of the sulfate soil over that of the muriate soil, which

is striking, may be due to the previous saturation for 24 hours; but it may also be due to the places on the plots from which the samples came. These lots of soil were not composite samples from their respective plots, but were small cores removed bodily and unmixed with other similar cores.

Only a trace of potassium could be found in the percolates. Chlorine and sulfuric acid varied as would be expected in accordance with the potash salt used. Sodium did not vary between the two plots, but calcium was notably less concentrated in the percolates from the muriate soil. This may be attributed to its greater solubility as calcium chloride and early removal after application of the fertilizer; but it also ties up with the higher amount of calcium obtained from the muriate soil in weak HNO_3, and by fusion.

An absorption study was made with the assistance of Mr. Beals in the winter of 1916, to learn what the immediate effects were of solutions of potassium chloride and potassium sulfate respectively, on the two soils of field B. The soils were from the two series of plots, 11, 15 and 17 forming the muriate samples, and 12, 16 and 18, the sulfate samples. The soil samples were those already mentioned as secured in November, 1915.

Two hundred grams of the muriate soil were allowed to stand in contact with 1000 cc. 0.1 N KCl in a large flask, for 48 hours, while 200 gms. of the sulfate soil were in contact with 1000 cc. 0.1 N K_2SO_4. During working hours, the mixtures were frequently shaken, and at the end of the period, the solutions were filtered and analyzed. The period of time was too short to produce equilibrium; but it should show the direction of the reaction between the potassium salts and the soils.

Potassium was absorbed more freely from the KCl than from the K_2SO_4. A little of the Cl was retained by the soil, probably by adsorption of unchanged KCl; but from the sulfate soil there was actually extracted SO_4 in addition to that contained as K_2SO_4.

Less Ca was removed by the KCl, which instead appeared to exchange places with Na, since there was much more sodium in the chloride solution than in the sulfate solution.

Al, Fe and Mn were found in traces in the solutions. This removal of sodium instead of calcium by the chloride solution is in harmony with the differences observed between the calcium results in the other studies.

The experiments were repeated in full, so that results were obtained on the six individual samples in duplicate. Absorption experiments are difficult to execute with closely parallel results, since the phenomena are both physical and chemical and invariable conditions are nearly impossible to maintain. The results all deviated in the same direction however, and the averages given in the table undoubtedly show the relative behavior of the two solutions on their respective soils.

Water extracts were made from each of the 1915 soil samples by shaking 50 gms. of soil with 500 cc. of water   The shaking was done at short intervals during an hour, and then the mixture was filtered through a small paper

fitted into a 3-inch funnel. The paper and a portion of the funnel were at
once filled with the soil, and the filtrate was refiltered through the mass until
clear. Thus the solution was practically a filtrate through soil supported
by a small paper that was soon saturated with absorbed salts.

Portions of the extracts were concentrated in platinum dishes, after the
addition of a few drops of phenolphthalein. The extracts from 11, 12, 15
and 16 turned pink when the volume had been condensed to less than one-
fourth, while that from 17 turned just before dryness and the extract from 18
failed to change. In this qualitative comparison the extracts from the muri-
ate soils were slightly ahead of those from the sulfate soils in reaching al-
kalinity. The effect on the indicator during concentration is doubtless due
to the hydrolysis of calcium bicarbonate or calcium silicate.

Samples from the same plots taken one year later, in November, 1916,
were extracted with water in the manner just described. Concentration of

TABLE 6

Absorption experiments with soils of field B

Muriate soils treated with 0.1 N KCl, sulfate soils with 0.1 N K₂SO₄. Absorption and extrac-
tion in milligrams per 100 grams soil

	MURIATE SOIL	SULFATE SOIL
	mgm.	*mgm.*
K absorbed......................................	204	161
Cl absorbed......................................	19	...
SO₄ extracted....................................	...	103
Ca extracted.....................................	47	55
Mg extracted.....................................	6	8
Na extracted.....................................	169	55

Traces of Al and Fe in all solutions.   Trace of Mn found in but one solution from Plot 18.

portions of these extracts were made in platinum dishes, after addition of
rosolic acid as an indicator. The extracts from 11 and 12 quickly turned
to the neutral tint of this indicator but failed to show any alkalinity on fur-
ther evaporation to dryness. The extracts from 17 and 18 retained the yel-
low or acid tint of the indicator throughout the operation. Apparently in
the intervening year, the residual calcium carbonate had disappeared from
these soils. Extracts were not prepared from plots 15 and 16.

The hydrogen-ion concentration was measured colorimetrically in these
four extracts. The pH values were between 6.2 and 6.4, and the tints of
the muriate solutions matched those of the corresponding sulfate solutions.

SUMMARY AND CONCLUSIONS

Soil from three plots treated for 22 years with muriate of potash, has been
compared in its chemical behavior with soil from 3 adjacent plots treated
during the same time with sulfate of potash.

Analyses of these soils showed slightly more lime in the muriate series when determined by fusion and by 0.2 N HNO_3. All other results were practically alike in both soils.

Percolation experiments with columns of soil taken directly from the plots, yielded slightly more total solids from the muriate series, while the sulfate series gave the higher lime. A tenth-normal solution of K_2SO_4 dissolved more Ca from the air-dry sulfate soils than a similar solution of KCl removed from the muriate soils. The KCl solution removed more Na than Ca.

The reactions of water-solutions of the soils were very slightly acid, and least in those from the muriate soils.

It is concluded that the long continued use of the two potash salts produced no important cumulative differences in the chemical properties of this soil, and that muriate of potash is no more and possibly less exhaustive of lime in the soil than sulfate of potash.

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THE INFLUENCE OF THE NITROGEN TREATMENT ON THE CONTENT OF NITROGEN, CARBON AND PHOSPHORIC ACID IN A SOIL VARYING IN MECHANICAL COMPOSITION[1]

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The soil under observation was cropped for 10 years in cylinders of the type used at this station, in carrying out a study of the influence of the mechanical composition of the soil on the availability of nitrogen in nitrate of soda and dried blood (2).

The soil is a loam belonging to the Penn series and was modified for this work by introducing varying percentages of a rather coarse sand. Thus in addition to the loam soil alone, there were mixtures of this containing 10, 20, 30 etc. up to 100 per cent of sand (the 60 per cent sand mixture was omitted).

With the exception of 1911 when corn was grown, two crops have been grown each year for the 10 years. All of the cylinders received liberal applications of acid phosphate and muriate of potash, and lime was applied at intervals, so that acidity was not a limiting factor.

For each soil mixture two cylinders received no nitrogen, two received nitrate of soda at the rate of 320 pounds per acre and two received dried blood equivalent to the nitrate of soda. The fertilizers were applied annually to the first crop.

With the completion of the work in the fall of 1920, samples of soil were collected from all of the mixtures and these have been analyzed for total nitrogen, carbon and phosphoric acid. The analytical results are shown in table 1 along with the average yields of dry matter for the 9 years—1912 to 1920 inclusive (the figures for the corn of 1911 are included but are omitted from the averages).

A study of these figures shows that the yields from the check cylinders (no nitrogen) are much lower than those from cylinders where nitrate of soda and dried blood were used. In a number of cases the latter were more than twice as large as the former. This is shown by the final averages. The 9 year average of all check cylinders was 57.6 gm.; of all nitrate of soda cylinders 132.6 gm., and of all dried blood cylinders 120 gm. The highest average yield for the nitrate of soda cylinder was on the 10 per cent sand series. Up to 30 per cent sand the decrease in yield was slight. From this point on, there is, with one exception, a gradual decline in yield.

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It is interesting to compare these figures giving the yields of dry matter, with the figures for the total nitrogen in the soil, for the three treatments at the end of the 10-year period. From an examination of the table it is at once apparent that there is very little difference between the nitrogen content of the soils that received no nitrogen during the 10 years and those that received the nitrate of soda and dried blood treatment. To take a specific case the check cylinders with 50 per cent sand show a nitrogen content of 0.0583 per cent nitrogen, whereas the corresponding nitrate of soda cylinders show 0.0608 per cent nitrogen. The difference is so slight that it is easily within the limit of error. The average yield for the nitrate cylinders however is more than twice as great as the average for the check. Furthermore,

TABLE 1

The influence of the nitrogen treatment on the yield of dry matter and the composition of the soil

SOIL MIXTURE	YIELD OF DRY MATTER, 9 YEAR AVERAGE			TOTAL NITROGEN IN SOIL AFTER 10 YEARS OF CROPPING			TOTAL CARBON IN SOIL AFTER 10 YEARS OF CROPPING			TOTAL PHOSPHORIC ACID AFTER 10 YEARS OF CROPPING		
	Check	NaNO$_3$	Dried blood	Check	NaNO$_3$	Dried blood	Check	NaNO$_3$	Dried blood	Check	NaNO$_3$	Dried blood
	gm.	gm.	gm.	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Loam soil....	81.4	157.0	147.9	0.1103	0.1112	0.1049	1.123	1.120	0.990	0.175	0.175	0.164
10% sand....	89.3	164.5	149.9	0.0900	0.0980	0.0964	0.958	0.853	0.993	0.155	0.154	0.167
20% sand....	70.5	152.4	135.6	0.0793	0.0848	0.0843	0.750	0.930	0.870	0.145	0.151	0.148
30% sand....	68.6	156.4	137.2	0.0673	0.0705	0.0776	0.675	0.783	0.838	0.145	0.130	0.129
40% sand....	65.4	153.3	130.7	0.0618	0.0660	0.0681	0.868	0.773	0.855	0.130	0.130	0.132
50% sand....	68.6	152.1	126.8	0.0583	0.0608	0.0634	0.725	0.765	0.810	0.127	0.123	0.133
70% sand....	46.1	134.9	110.5	0.0300	0.0332	0.0382	0.343	0.440	0.445	0.118	0.116	0.106
80% sand....	42.0	110.5	107.7	0.0240	0.0252	0.0307	0.333	0.308	0.373	0.108	0.097	0.112
90% sand....	27.9	97.8	88.3	0.0159	0.0181	0.0201	0.228	0.295	0.358	0.079	0.090	0.107
100% sand...	16.3	47.2	65.0	0.0093	0.0107	0.0093	0.215	0.195	0.150	0.073	0.075	0.054
Average...	57.6	132.6	120.0	0.0546	0.0579	0.0593	0.622	0.646	0.668	0.126	0.124	0.125

the 50-per-cent-sand cylinders gave an average yield of 152.1 gm. of dry matter as against an average of 157 gm. for the loam soil, notwithstanding the fact that the latter contains nearly twice as much nitrogen as the former.

With the 80-per-cent-sand mixture the nitrate of soda cylinders gave an average yield of 110.5 gm. of dry matter as against an average of 42 gm. for the check cylinders, although the percentage of total nitrogen in these two soils differs by only 0.0012 per cent.

The figures for total carbon in the soil are quite parallel to those for total nitrogen. Here again the differences between the percentage of carbon in the check cylinders and the nitrate of soda cylinders falls within the limit of error. It may be pointed out that roughly speaking, up to and including

the 70-per-cent-sand mixture, there is about 10 times as much carbon in these soils as there is nitrogen.

It is of interest to note that the average percentage of nitrogen and carbon for all the soil mixtures is slightly higher with dried blood than with nitrate of soda, whereas the figures for the average yields of dry matter are just the reverse.

Here then is a series of soil mixtures a part of which have received for 10 years nitrogenous fertilizers equivalent to 320 pounds of nitrate of soda per acre and others which have received no nitrogenous treatment during this period, and at the close of the period the difference between the total nitrogen and carbon content of the treated and untreated soils is very slight. At the same time the nitrogen treated soils have yielded on an average more than twice as much crop substance as the untreated soils. The fact that there has been no appreciable increase in the nitrogen content of the soils that have received the nitrogen fertilizers, over those that have received no nitrogen for 10 years, would lead one to conclude that the applied nitrogen has constituted a "revolving fund" which was being drawn upon to the full extent, by the crops and by the forces which either destroy nitrogen compounds or cause them to leach away. In other words, under the cropping system used there could be no appreciable accumulation in the soil of the applied nitrogen. The averages do indicate a very slight tendency towards accumulation, but this may be an apparent rather than a real difference.

If there remains any doubt in the mind of anyone as to the failure of a chemical analysis of the soil, taken alone, to determine its crop-producing power, certainly these figures should dispel such doubt.

It is quite evident from these results that a soil which is low in total nitrogen may be quite productive if the supply of available nitrogen is well maintained during the growing period. On the other hand a soil may show a high percentage of total nitrogen while at the same time it produces low yields, due to a deficiency of available nitrogen.

The work bears out, in a striking manner, the conclusion which Hilgard (1) reached nearly 20 years ago, namely, "The impossibility of judging correctly of a soil's productiveness from the percentage of chemical ingredients alone."

A soil of the character of the 40 or 50 per cent sand mixture, having a low percentage of total nitrogen, may give good yields if available nitrogen is applied at the right time. However, it does not follow that this is an economical method of getting good yields. It frequently pays to "build up" the total nitrogen, so that there may be a larger natural supply of available nitrogen; but this, it must be remembered, is a slow process, especially in the case of sandy soils where bacterial decomposition goes on rapidly. It is under such conditions that careful attention must be given to the "revolving" supply, that is the available nitrogen.

Russell (3) has pointed out that so far as our present knowledge goes it is impossible to maintain a high content of nitrogen on cultivated land except

at a wasteful expenditure of nitrogenous manure. In another place Russell (4) expresses the thought that the yield of crops under British conditions was perhaps more limited by the amount of nitrate present than by any other single factor.

Apparently the nitrogen treatment has had no influence on the phosphoric acid content of the soil. In practically every case, for a given soil mixture, the percentage of phosphoric acid is essentially the same for the three treatments. The average percentage of phosphoric acid for all the mixtures that received no nitrogen (check) is 0.126 per cent; the average for those that received nitrate of soda is 0.124 per cent and for those that received dried blood 0.125 per cent.

In this connection it will be remembered that the phosphoric acid treatment was uniform for all cylinders and since the nitrate of soda and dried blood cylinders yielded larger crops than the check cylinders, it necessarily follows that the crops from the former removed more phosphoric acid than the crops from the latter. Since the analysis shows that there was no essential difference in the phosphoric acid content of the soils at the end of the 10 year period, it seems reasonable to conclude that the check cylinders have lost more phosphoric acid through leaching than the nitrogen treated cylinders. This is what we should expect. With diminished crops there is greater opportunity for loss through leaching. The smaller the root system the less the amount of organic matter to catch and hold dissolved mineral matter.

SUMMARY

For a period of 10 years equivalent amounts of nitrogen in the form of nitrate of soda and dried blood were compared in cylinder experiments on a soil varying in mechanical composition, from a loam to a coarse sand.

With the exception of the first year, two crops were grown each year, the fertilizer in every case being applied for the first crop.

The 9-year average yields of dry matter are reported for the check treatment (no nitrogen), nitrate of soda treatment and dried blood treatment.

These yields are compared with the percentage of nitrogen, carbon and phosphoric acid, in the various soil mixtures, at the end of the ten years.

Attention is called to the wide difference in the yields of dry matter on the check cylinders as compared with the nitrogen treated cylinders, and the slight difference in the percentage of nitrogen and carbon in the soils from the cylinders receiving the three different treatments.

The work emphasizes very strongly the importance of available nitrogen as distinct from total nitrogen, and likewise the failure of the determination of the chemical ingredients of a soil in forcasting the productiveness of that soil.

The phosphoric acid content is essentially the same in the soils without nitrogen treatment as in those which received the nitrate of soda and dried blood treatments.

There is indirect evidence that the check cylinders lost more phosphoric acid through leaching than the nitrogen treated cylinders.

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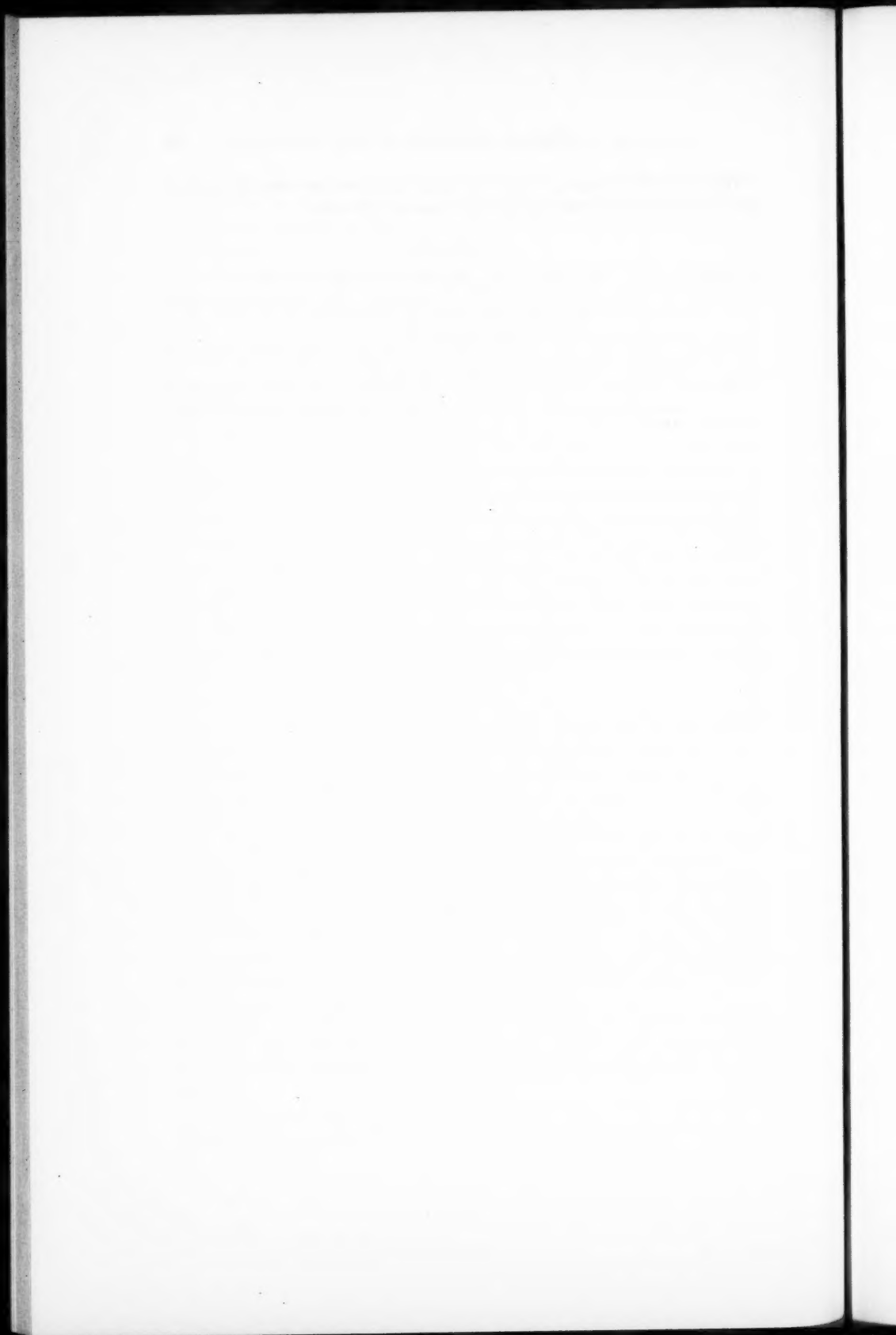
EFFECT OF DRYING AND STORAGE UPON THE HYDROGEN-ION CONCENTRATION OF SOIL SAMPLES[1]

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INTRODUCTION

The data hitherto published would indicate that the practice of using air-dry soil samples for hydrogen-ion determinations is satisfactory, especially if these are acid. Our studies lead us to conclude, however, that the only reliable indication of conditions existing in the field are obtained when hydrogen-ion determinations are made with soils samples taken freshly from the field.

Burgess (2) working with Miami silt loam from a series of plots at the Rhode Island Station found that both air-drying and oven-drying had little or no effect upon the pH values of acid soils but that drying alkaline soils rendered them somewhat less alkaline. Arrhenius (1), reporting the effect of drying on the hydrogen-ion concentration of one alkaline soil, found that neither air-drying nor drying by heat at 100°C. and 150°C. brought about any change in pH values as determined by the indicator method.

Preliminary determinations showed that some of the Minnesota soils with which we were working changed considerably in pH values upon becoming air-dry. Later we have made determinations on many of our samples both while still fresh and moist from the field and again after allowing them to become air-dry. With a small number we have studied the effect of oven-drying at 110°C. of moistening with distilled water after air-drying, and of storage in moist condition in air-tight glass containers. The effect of drying upon the indication of acidity as shown by the qualitative potassium thiocyanate method was also tested.

The hydrogen-ion concentration determinations were made by the gas chain electrometric method, using a modification of Knight's electrode vessel (3) with bubbling hydrogen and constant mechanical shaking. Double electrodes inserted in the vessel afforded an opportunity for checking the correctness of each determination. The electrodes were checked against a standard soil at the beginning of each run and all potentiometer readings were calculated to 25°C.

EFFECT OF AIR-DRYING

The effect of air-drying upon samples taken from the same field but from plots having different lime or marl treatment is shown in table 1. The fields from which these samples were taken are some upon which liming experiments are in progress. The soils of these fields range in texture from silty clay loam to loamy sand. Where the samples became less acid on drying the difference is indicated by a minus (−) sign.

In the case of fields A and B the difference in hydrogen-ion concentration between moist and air-dry soil is not great nor is the difference between individual samples marked. The samples from field C showed a slightly greater difference but not a marked variation from the average, while those from fields

TABLE 1

Hydrogen-ion concentration of fresh and air-dry soil samples from five experimental fields

SAMPLE NUM-BER	FIELD A, SILT LOAM (WATER-LAID)			FIELD B, SILTY CLAY LOAM (GLACIAL)			FIELD C, SILT LOAM (LOESSIAL)			FIELD D, LOAMY SAND (GLACIAL OUTWASH)			FIELD E, SILTY CLAY LOAM (GLACIAL)		
	Fresh	Air-dry	Difference	Fresh	Air-dry	Difference	Fresh	Air-dry	Difference	Fresh	Air-dry	Difference	Fresh	Air-dry	Difference
	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH
1	5.75	5.61	0.14	5.78	5.74	0.04	5.58	5.24	0.34	5.50	5.79	−0.29	5.54	5.14	0.40
2	5.77	5.73	0.04	5.87	5.95	−0.08	5.71	5.36	0.35	5.83	6.32	−0.49	5.65	5.29	0.36
3	5.80	5.95	−0.15	5.88	5.83	0.05	5.88	5.48	0.40	6.29	6.39	−0.10	5.65	5.48	0.17
4	5.88	5.88	0	5.90	5.76	0.14	6.07	5.61	0.46	6.54	6.12	0.42	5.87	5.54	0.33
5	6.04	5.95	0.09	5.90	5.80	0.10	6.22	6.17	0.05	6.54	6.44	0.10	6.04	5.61	−0.43
6	6.07	5.95	0.12	6.02	5.85	0.17	6.48	6.27	0.21	7.34	7.30	0.04	6.26	5.11	1.17
7	5.99	6.19	−0.20	6.04	5.95	0.09	6.63	6.51	0.12	7.37	7.66	−0.29	6.36	5.95	0.41
8	6.05	5.97	0.08	6.19	6.07	0.12	7.51	7.13	0.38	7.54	7.56	−0.02	6.54	5.90	0.64
Average			0.07			0.08			0.29			−0.07			0.49
Range.........			0.29			0.25			0.41			0.91			1.00

D and E showed a wide range in the difference between moist and air-dry soil and a few instances of large differences between the two conditions of moistness. The acid samples showed as great a change on air-drying as did the alkaline ones. Some of the samples became more acid and others more alkaline on drying but most frequently they became more acid. From the data it appears that a constant difference between moist and air-dry samples cannot be assumed for any individual field without establishing this by a sufficient number of preliminary determinations.

In table 2 are reported the pH values of moist and air-dry samples of glacial and loessial soils taken from well distributed localities in Minnesota. The samples, from a depth as great as six feet, were divided into two groups, surface and subsoil, all samples taken below the surface six inches being included under the designation of subsoil. A pH value of 7.07 was taken as neutrality. The

samples were divided into groups having a difference in pH of 0.5 and ranging from 5.08 to 9.57.   The glacial soils show a more marked increase in acidity upon drying than do the loessial.   The greatest difference in the case of the surface soils of the glacial group occurred in those soils with original pH values 6.58 to 7.07.   The samples with pH values of 6.08–6.57 and 6.58–7.07 showed more change than those of the two groups between pH 7.08 and pH 8.07.   With the subsoils the changes became more marked as the soils became more alkaline.   The acid soils of both the surface and subsoil groups showed considerable change upon air-drying.

TABLE 2

Hydrogen-ion concentration of fresh and air-dry glacial and loessial soil samples

RANGE IN pH VALUES	DIFFERENCE IN pH VALUES OF FRESH AND AIR-DRY LOESSIAL SOIL				DIFFERENCE IN pH VALUES OF FRESH AND AIR-DRY GLACIAL SOIL			
	Number samples tested	Minimum	Maximum	Average of all	Number samples tested	Minimum	Maximum	Average of all
Surface soil								
5.08–5.57	3	0.24	0.57	0.39	2	0.12	0.25	0.18
5.58–6.07	16	−0.05	0.73	0.39	14	0.11	0.64	0.36
6.08–6.57	9	0.32	1.24	0.64	3	0.56	0.86	0.74
6.58–7.07	3	0.48	0.73	0.62	1	1.05	1.05	1.05
7.08–7.57	0				2	0.65	0.66	0.66
7.58–8.07	0				1	0.74	0.74	0.74
Subsoil								
5.08–5.57	1	0.52	0.52	0.52	1	0.25	0.25	0.25
5.58–6.07	8	0.07	0.71	0.31	15	0.16	0.94	0.50
6.08–6.57	8	0.20	0.98	0.57	12	0.25	1.38	0.68
6.58–7.07	3	0.18	0.80	0.50	5	0.44	1.21	0.84
7.08–7.57	1	0.52	0.52	0.52	11	0.51	1.17	0.72
7.58–8.07	0				13	0.43	1.38	0.89
8.08–8.57	0				6	0.42	1.54	0.91
8.58–9.07	0				5	0.98	1.19	1.11
9.08–9.57	0				1	0.98	0.98	0.98

The loess soils showed a fairly constant change in hydrogen-ion concentration for surface soil and subsoil and for both acid and alkaline samples.

In determining the effect of air-drying upon the reaction obtained by the qualitative potassium thiocyanate method, approximately 10 gms. of soil were placed in a test tube, 10 cc. of a saturated ethyl alcohol solution of potassium thiocyanate added, the test tube stoppered and thoroughly shaken. After standing 15 minutes the color of the supernatant liquid was observed.   It was found possible to distinguish five degrees of acidity which may be designated: very slight, slight, medium, strong and very strong. The reaction of both the fresh and air-dry soil was determined with 76 samples. Five, all

of which were neutral, showed no change while 71 became more acid upon air-drying. The amount of change bore no relation to the degree of acidity. Thirty-five samples changed one degree, nineteen changed two degrees, and seventeen changed three degrees.

EFFECT OF OVEN-DRYING

The effect of oven-drying upon the hydrogen-ion concentration as compared with air-drying is shown in table 3. For all the samples tried over-drying rendered both acid and alkaline soils more acid than when fresh and in all but four cases more acid than when air-dry. This effect was more pronounced with the samples of loess and sandy soil from glacial outwash, than with the glacial soils.

TABLE 3

Hydrogen-ion concentration of fresh, air-dried and oven-dried soil samples

SAMPLE NUMBER	GLACIAL			GLACIAL OUTWASH			LOESSIAL		
	Fresh	Air-dry	Oven-dry	Fresh	Air-dry	Oven-dry	Fresh	Air-dry	Oven-dry
	pH	pH	pH	pH	pH	pH	pH	pH	pH
1	5.60	5.58	5.04	6.32	5.33	5.21	5.85	5.63	4.60
2	6.12	5.90	5.75	6.37	5.75	5.55	5.87	5.80	5.33
3	6.20	5.90	5.55	6.78	6.34	6.18	5.90	5.75	5.16
4	7.30	6.64	7.13	6.96	6.22	5.98	5.97	5.70	4.92
5	8.00	7.39	7.79	7.00	6.39	6.17	6.32	5.90	5.19
6	8.40	7.96	8.00	7.11	6.48	6.26	6.46	6.26	5.99
7	8.79	8.34	8.30	7.20	6.54	6.04	6.63	6.12	5.34

EFFECT OF MOISTENING AIR-DRY SAMPLES

In order to determine whether samples would return to their original hydrogen-ion concentrations and in what measure if moistened after air-drying and allowed to temper, a set of the air-dry samples was moistened with distilled water and placed in air-tight glass containers. The hydrogen-ion concentrations were determined at the end of 1, 3, 23, 40 and 60 days and are reported in table 4. At the end of 1 and 3 days the two samples tested were still more acid than the original moist samples and all were set aside for 20 days. At the end of this time all were decidedly more acid than the air-dry samples with the exception of no. 7 and at the end of 40 and 60 days there was little further change. Thus it appears that soils which have become air-dry when remoistened and allowed to temper have a hydrogen-ion concentration no more nearly correct than the air-dry samples.

EFFECT OF STORAGE IN MOIST CONDITION

The effect of storage of fresh moist soils in air-tight containers on the hydrogen-ion concentration is shown in table 5. The change in pH values

varies from 0.02 to 0.64 with a range of 1.24 (−0.64 to +0.60). There is no relation in this case between the degree of acidity or alkalinity and the ultimate reaction. It would appear that soils kept in storage in this manner for any length of time are no more valuable than if they were allowed to become air-dry.

TABLE 4

Hydrogen-ion concentration of fresh, air-dried and remoistened soil samples

SAMPLE NUMBER	FRESH	AIR-DRY	REMOISTENED AND TEMPERED:				
			1 day	3 days	23 days	40 days	60 days
1	5.44	5.19	....	....	5.26	5.33	5.28
2	5.60	5.46	....	....	5.07	5.09	5.04
3	6.07	5.82	....	....	5.34	5.38	5.29
4	6.14	5.92	....	....	5.38	5.39	5.31
5	6.20	5.90	....	....	5.55	5.50	5.50
6	6.32	5.90	6.15	5.90	5.12	5.09	5.02
7	7.19	6.54	6.93	6.92	6.14	6.09	6.15

TABLE 5

Hydrogen-ion concentration of fresh and stored samples of soil

SAMPLE NUMBER	FRESH	AFTER 3 MONTHS	DIFFERENCE	SAMPLE NUMBER	FRESH	AFTER 3 MONTHS	DIFFERENCE
	pH	pH	pH		pH	pH	pH
1	5.36	4.97	+0.39	11	6.27	5.95	+0.32
2	5.56	5.63	−0.07	12	6.27	6.05	+0.22
3	5.61	5.53	+0.08	13	6.48	6.37	+0.11
4	5.71	5.51	+0.20	14	6.54	7.10	−0.64
5	5.75	5.31	+0.44	15	6.54	6.07	+0.47
6	5.90	6.54	−0.64	16	6.66	6.64	+0.02
7	6.00	5.87	+0.13	17	6.91	6.83	+0.08
8	6.04	5.64	+0.40	18	7.51	7.22	+0.29
9	6.22	6.15	+0.07	19	7.96	7.52	+0.44
10	6.26	5.66	+0.60	20	8.05	7.56	−0.49

SUMMARY

The effect of air-drying and oven-drying upon the hydrogen-ion concentration of soil samples was determined as was also the effect of moistening and tempering samples of soil which had become air-dry and of storing the fresh moist samples in air-tight containers. The effect of air-drying upon the reaction of soil samples was tested also by the qualitative potassium thiocyanate method.

Soil samples from five fields upon which liming experiments are in progress showed differences in the pH values between the fresh and air-dry samples varying from pH 0.03 to pH 1.17. With two fields the differences were small; with two others, large; and with one, intermediate. The acid samples showed

as great a change upon air-drying as did the alkaline ones. Some samples became more acid and some more alkaline upon air-drying but the general tendency was to become more acid.

Of 144 glacial and loessial soils tested in the fresh and air-dry condition all except one became more acid upon air-drying. With the glacial subsoils the difference between the fresh and air-dry samples tended to increase as the pH increased. The maximum difference, pH 1.11, was found with the group having pH values of 8.58 to 9.07. The loess subsoils did not show this tendency. The glacial soils, in general, showed a more marked change from air-drying than the loess.

Permitting soil samples to become air-dry in most cases increased the intensity of the reaction obtained by the qualitative potassium thiocyanate method. Of the 76 samples tested, 5 showed no change, 35 a change of one degree of acidity, 19 a change of 2 degrees and 17 a change of 3 degrees.

Oven-drying rendered all soil samples tested more acid than in the fresh condition. Of twenty-one samples tested all except four were more acid than when in the air-dry condition.

Samples air-dried, then moistened with distilled water and tempered were more acid than the same soils in fresh condition. Of the seven samples tried all but one were found more acid than when in the air-dry condition.

The hydrogen-ion concentration of fresh moist soils stored for three months in air-tight glass containers changed in most cases, some samples becoming more acid and some less so, with a general tendency to become more acid. The amount of change is not related to the degree of acidity or alkalinity.

From the data reported it is concluded that the only reliable indication of conditions existing in the field are obtained when hydrogen-ion concentration determinations are made with soil samples freshly taken.

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EFFECT OF SULFUR, CALCIUM AND PHOSPHORUS ON THE YIELD AND COMPOSITION OF ALFALFA ON SIX TYPES OF IDAHO SOILS[1]

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Recent investigations have indicated that many soils are apparently deficient in sulfur. Some soils have shown greatly increased alfalfa yields with applications of calcium sulfate; others, with elemental sulfur. In the case of gypsum the increased yields have been attributed to sulfur, lime, or in some cases to a stimulating effect on the soil itself. Much data on record seem to show that gypsum has increased the amount of soluble plant-food in the soil extract (chiefly potassium) while on the other hand an equal amount of data can be found which controverts this view. When all data are reviewed, one arrives at the conclusion that both views are in a measure correct, for there is no doubt that different soil types respond differently to applications of gypsum. The real effect of gypsum and calcium carbonate on soils is aptly expressed by Lipman and Gericke (6). They state "All soils do not behave alike when treated with $CaSO_4$ or $CaCO_3$. They should not be expected to do so considering their mineral composition, the law of chemical equilibrium, and the nature of colloid action in soils."

This work was started on six of the principal soil types of the state in order to determine their need, if such existed, for certain fertilizers and amendments. The soils used in this experiment are Moscow loam, Helmer silt loam, Sandpoint soil, Aberdeen soil, Boise silt loam and Palouse silt loam. They are described as follows:

Moscow loam. The sample used in this experiment was obtained from an area southeast of Moscow which was shown to be well within the area mapped under that series in the Latah County Soil Survey (1). The Moscow series is described therein as a residual soil "the surface of which is of light brown to brown in color, with light grayish brown to yellowish brown variations. They overlie subsoils of grayish yellow or yellowish brown to pale yellow color." The deeper subsoils frequently consist of disintegrated rock and grade into a substratum of bed rock. The soils of this series are developed from weathering of granites, schists, gneisses or quartzites though influenced in some localities by admixtures of fine grained loessial or windlaid material." The sample was taken from a field that had been in wheat for several years.

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[1] The work presented in this paper was carried out as a coöperative project between the departments of agricultural chemistry and agronomy.

Helmer silt loam. "The soils of the Helmer series (1) are pale yellow to yellow in color with light grayish-yellow to brownish-yellow variations. The upper subsoils are usually of slightly lighter yellow to grayish-yellow color; the deeper subsoils are similar or slightly darker in color and usually compact, the structure in places approaching a hard pan in densely forested areas. The surface material under dry field conditions sometimes assumes a light grayish or bleached appearance, this being most noticeable on slopes where the grayish compact subsoil has been exposed. The Helmer soils are low in organic matter. They are derived from aeolian deposits and the soil and subsoil material is non-calcareous. The topography is gently rolling to undulating and drainage is well developed. The areas under cultivation have been cleared of timber and much of the series is still in forest." The sample used in these experiments was taken from a field that had been under cultivation for a number of years.

Sandpoint soil. The sample obtained from the Sandpoint Substation is not included in any of the soil maps of Idaho. The soil is characteristic of the timbered areas of the northern portion of this state having supported a heavy growth of white pine and other coniferous trees. In texture this soil would be classed as silt loam. The surface soil is yellow to yellowish-brown in color and is characterized by a lack of lime. The subsoils are lighter in color, in places very fine in texture approaching a shale. The subsoil varies in different parts of the area and is usually well supplied with lime, especially below the third foot.

The area from which this sample was taken is included in the Purcell Trench which extends from the southern end of Lake Coeur d'Alene to the 49th parallel. The soils have been formed from materials deposited under lacustrine conditions existing subsequent to the glacial period. The sample used came from a freshly cleared field which was being prepared for the first crop.

Aberdeen soil. The sample obtained from the Aberdeen substation is not included in any of the soil maps of Idaho. These soils are of mixed origin having been formed from the disintegration of the underlying basalt together with windblown material carried into the region. The surface is a yellowish-buff of fine sandy loam underlaid by a subsoil of very similar material to a depth of three feet or more. The subsoil contains streaks of sand from two to six inches in thickness found at a depth of 3 feet or more. This soil originally supported a growth of sage brush and other desert vegetation. The field from which the sample was taken had grown several crops of alfalfa and small grains.

Boise silt loam. The sample of soil taken from the Caldwell Substation farm near Caldwell is mapped (5) by the Bureau of Soils as Boise sandy loam. This type was later changed to Boise silt loam. The particular sample used in this work is a very fine sandy loam. It is described as "a grayish colored light sandy loam with a soft, ashy feel carrying a large amount of silt and having an average depth of about 2 feet. The subsoil of this type south of the Boise River is a loam or clay loam which has an average depth of about 18 to 24 inches. This is underlain by a sandy loam, sand or gravel cemented together into calcium carbonate to form a hardpan." The sample used came from a field that had been under cultivation for several years. A rotation including alfalfa, corn and small grains had been practiced.

Palouse silt loam. The sample of Palouse silt loam soil was taken from one of the fields on the University farm. This soil is described (1) as follows: "The soil of the Palouse silt loam to a depth of 8 to 14 inches is a dull brown or dark brown silt loam, underlain to a depth of 36 to 40 inches by a brownish-yellow to brown or light brown silt loam or silty clay loam, which usually grades into a silty clay or a silty clay loam in the lower subsoil. The lower subsoil is usually yellowish-brown or brownish-yellow, lighter in color than the intermediate and rests upon a tawny-yellow substratum of homogeneous and unstratified loessial deposit of fine texture from which the soil material is derived. This rests upon underlying bedrock at depths ranging from a few feet to 50 feet or more. The surface soil is high in organic matter and when wet is nearly black in color. The brown tint is more pronounced under dry field conditions." The sample used consisted of the surface 8 inches taken from a field in which a rotation including peas, corn and wheat had been followed with a dressing of manure every second or third year.

The moisture equivalent of each of the soil types used in this experiment were determined by the method of Briggs and McLane (3).   The total sulfur content of each soil was determined by the sulfur bomb method (7) and expressed as percentage of anhydrous soil.   These results are given in table 1.

TABLE 1

Total sulphur and moisture equivalents of soils

SOIL TYPE	TOTAL SULFUR CONTENT	MOISTURE EQUIVALENT
	per cent	*per cent*
Moscow loam...	0.007	25.0
Helmer silt loam.....................................	0.008	24.9
Sandpoint..	0.016	39.7
Aberdeen...	0.017	17.9
Boise silt loam.......................................	0.019	20.4
Palouse silt loam.....................................	0.023	26.1

PLAN OF EXPERIMENT

Three-gallon stone jars were filled with soil and treated with fertilizers and amendments at the following rates per acre:

1. 2000 pounds lime
2. 2000 pounds lime, 100 pounds sulfur
3. 100 pounds sulfur
4. 200 pounds gypsum
5. 200 pounds Treble Superphosphate
6. 500 pounds sulfur (to all soils except Moscow loam and Aberdeen)
7. 300 pounds raw rock phosphate, (to all soils except Moscow loam and Aberdeen)

These materials were intimately mixed with the top four inches of soil.   Check pots without applications of fertilizers were, of course, included in the series for each soil.   The treatments were made in triplicate.   Alfalfa was grown on two of the three pots while the third pot was kept in a fallowed condition.   Since this was a greenhouse experiment it was possible to make seven successive cuttings which was done with all of the cropped pots except certain ones containing sandpoint soil.   The cuttings were made as in common farm practice, i.e., when the new stalks began to appear.

The crop record is included in table 2 along with some data on the composition of the alfalfa.   Total sulfur was determined by the regular A. O. A. C. method (2).

DISCUSSION

Moscow loam.   This soil was lowest in total sulfur, containing 0.007 per cent, and closely corresponds to the Helmer silt loam which had 0.008 per cent sulfur. A slight increase in total yield of alfalfa over the check pots was obtained when 2000 pounds of lime were used.   The greatest increase in yield in this series was with the combination of 2000 pounds of lime plus 100 pounds of sulfur.

TABLE 2

Yield and composition of alfalfa as affected by soil treatments

SOIL TREATMENT PER ACRE	TOTAL DRY WEIGHT OF 7 CROPS (AVERAGE OF DUPLICATES)	INCREASE OF ALFALFA OVER CHECK	TOTAL SULFUR IN CROP	TOTAL NITROGEN IN CROP	TOTAL SULFUR IN ALL CROPS	TOTAL NITROGEN IN ALL CROPS
	gm.	*per cent*	*per cent*	*per cent*	*gm.*	*gm.*
Moscow loam						
No treatment................................	66.9	.....	0.145	2.60	0.097	1.74
Lime..	80.2	19.9	0.140	2.79	0.112	2.24
Lime and sulfur..............................	125.2	87.3	0.280	3.10	0.351	3.87
Sulfur......................................	97.6	45.9	0.345	3.06	0.337	2.98
Gypsum (CaSO₄)............................	114.6	71.3	0.320	3.27	0.367	3.75
Treble Superphosphate......................	115.7	73.0	0.165	3.00	0.191	3.47
Helmer silt loam						
No treatment................................	60.4	.....	0.140	2.60	0.084	1.57
Lime..	54.2	−10.3	0.180	2.91	0.974	1.57
Lime and sulfur..............................	118.6	96.4	0.330	3.53	0.393	4.19
Sulfur......................................	132.7	119.6	0.295	3.04	0.391	4.04
Sulfur, 500 lbs.............................	133.1	120.3	0.450	3.02	0.600	4.01
Gypsum.....................................	101.8	68.6	0.230	3.13	0.234	3.19
Treble Superphosphate......................	79.3	31.3	0.185	2.86	0.147	2.26
Raw rock phosphate.........................	74.0	22.5	0.205	2.86	0.152	2.12
Sandpoint						
No treatment................................	91.3	.....	0.185	2.93	0.168	2.67
Lime..	68.4	25.1	0.190	2.85	0.130	1.95
Lime and sulfur..............................	116.7	27.8	0.290	3.12	0.339	3.64
Gypsum.....................................	125.4	37.3	0.285	3.24	0.357	4.06
No treatment................................	51.7*	.....	0.230	3.37	0.118	1.74
Sulfur......................................	69.7*	34.8	0.390	3.70	0.272	2.57
Sulfur, 500 lbs.............................	76.7*	48.8	0.475	3.51	0.364	2.69
Treble Superphosphate......................	54.8*	6.0	0.250	3.38	0.137	1.86
Raw rock phosphate.........................	56.1*	8.5	0.250	3.37	0.140	1.89
Aberdeen						
No treatment................................	56.4	.....	0.300	3.02	0.169	1.70
Lime..	62.2	10.3	0.340	2.79	0.211	1.73
Lime and sulfur..............................	59.5	5.5	0.390	2.97	0.231	1.77
Sulfur......................................	74.5	32.1	0.395	2.97	0.294	2.21
Gypsum.....................................	65.5	16.1	0.370	3.06	0.242	2.00
Treble Superphosphate......................	98.4	74.4	0.210	2.94	0.206	2.89

* These totals represent four crops only.

TABLE 2—*Continued*

SOIL TREATMENT PER ACRE	TOTAL DRY WEIGHT OF 7 CROPS (AVERAGE OF DUPLICATES)	INCREASE OF ALFALFA OVER CHECK	TOTAL SULFUR IN CROP	TOTAL NITROGEN IN CROP	TOTAL SULFUR IN ALL CROPS	TOTAL NITROGEN IN ALL CROPS
	Boise silt loam					
	gm.	per cent	per cent	per cent	gm.	gm.
No treatment	81.2	.....	0.275	3.23	0.223	2.62
Lime	90.5	11.5	0.305	3.08	0.276	2.78
Lime and sulfur	79.8	−1.7	0.315	3.09	0.251	2.47
Sulfur	78.4	−3.4	0.435	3.15	0.341	2.47
Sulfur, 500 lbs	77.9	−4.1	0.460	3.37	0.358	2.62
Gypsum	82.4	1.5	0.440	3.12	0.362	2.56
Treble Superphosphate	101.9	25.5	0.340	3.34	0.346	3.40
Raw rock phosphate	79.9	−1.6	0.330	3.33	0.263	2.66
	Palouse silt loam					
No treatment	72.0	.....	0.170	2.86	0.122	2.06
Lime	97.6	35.6	0.160	2.83	0.156	2.76
Lime and sulfur	151.9	110.9	0.355	3.04	0.539	4.61
Sulfur	137.9	91.5	0.435	2.77	0.600	3.82
Sulfur, 500 lbs	126.3	75.4	0.470	2.59	0.594	3.27
Gypsum	129.1	79.2	0.345	2.58	0.445	3.33
Treble Superphosphate	65.3	−9.3	0.180	2.69	0.118	1.76
Raw rock phosphate	70.1	−2.6	0.150	2.35	0.105	1.64

Both sulfur alone and gypsum treatments resulted in increased yields, gypsum showing the greater effect. Treble Superphosphate (200 pounds per acre) caused slightly higher yields than gypsum. This phosphate fertilizer is high in available phosphoric acid, usually containing 46–48 per cent P_2O_5.

It is evident that lime alone did not produce an increase in sulfur content. Lime and sulfur in the combinations used in this experiment doubled the percentage of sulfur in the crop over that grown on the check. Sulfur alone caused the highest sulfur content and gypsum a sulfur content only slightly less. The application of Treble Superphosphate apparently had but little effect on the sulfur content of the crop which was in this case only slightly higher than the check.

The effect of the treatments on the nitrogen content is marked. All treatments caused an increased percentage of nitrogen in alfalfa. These increases were in the following order, reading from the lowest to the highest; check, 2000 pounds lime, 200 pounds Treble Superphosphate, 100 pounds sulfur, 2000 pounds lime and 100 pounds sulfur and 200 pounds of gypsum. When the total amount removed by crops is considered, the order is: check, lime alone, sulfur alone, Treble Superphosphate, gypsum and lime and sulfur.

Helmer silt loam. The Helmer silt loam contained 0.008 per cent sulfur. All applications except lime alone produced increased yields over the check soil, the sulfur applications producing the highest yields of all treatments. Five hundred pounds of sulfur produced a greater increase than 100 pounds. The yields with sulfur plus lime and with gypsum were still less. Both raw rock and Treble Superphosphate show an increase in yield.

' All treatments increased the percentage of total sulfur in the crop, the sulfur treatments most. The application of 500 pounds of sulfur produced alfalfa containing 50 per cent more sulfur than was found in the crop grown with the 100-pound application.

All treatments increased the percentage of nitrogen in the crop. Sulfur and lime caused the highest content and highest total removed by the crop, with the 100-pound application of sulfur, the 500 pounds of sulfur, and gypsum following in the order named for total nitrogen removed.

Sandpoint soil. With some treatments on this soil only four crops were grown because of lack of soil at the time the experiments were commenced. An additional check series was used in these cases. It is interesting to note that the average of the four crops and the average of the seven crops grown on the same soil were practically identical. The sandpoint soil contains .016 per cent of sulfur. Additions of 2000 pounds of lime reduced the yield to approximately one-fourth that secured on the check. Two thousand pounds of lime plus 100 pounds of sulfur increased the yield 27.8 per cent. Sulfur alone (100 pounds) increased the yield 34.8 per cent, and 500 pounds increased it 48.4 per cent, while gypsum caused an increase of 37.3 per cent. It is seen that sulfur alone, sulfur and lime, and sulfur in the form of gypsum all materially increase the yield of alfalfa. Raw rock phosphate increased the yield 8.5 per cent, while Treble Superphosphate caused a 6 per cent increase only.

In discussing the effect of the treatment on the sulfur and nitrogen content of the alfalfa, the reader must bear in mind that there are two checks, one for the seven crop series and one for the four crop series. Lime additions show practically the same sulfur content as the check. Sulfur applications, either with or without lime, or in the form of gypsum, all caused marked increases in the sulfur content of the crop. The heavier applications produced correspondingly heavy percentages of sulfur in the alfalfa, without increasing the nitrogen content over that produced by the lighter applications of sulfur. This might be taken as an indication that the lighter application of sulfur is sufficient for the number of crops grown. All treatments of lime and sulfur, gypsum and sulfur alone increased the nitrogen content of the alfalfa over the check.

Aberdeen soil. This soil contains .017 per cent of sulfur. Lime and sulfur and 2000 pounds of lime produced only slight increases in yield. Gypsum produced a slightly better increase. Sulfur alone caused a higher yield than any of these while Treble Superphosphate caused the highest yield of all.

The effect of these treatments on the sulfur content of alfalfa is quite marked. All treatments except Treble Superphosphate caused an increase in sulfur content. Phosphates lowered the percentage considerably with this soil.

The effect on the nitrogen content is not so marked in this series. The check crop had the highest nitrogen content except for pots treated with gypsum. For all other treatments, the nitrogen content was slightly lower than the check. When the total amount removed by the crops is considered, sulfur, gypsum, and phosphate applications all show increases over the check.

Boise silt loam. This soil shows a total sulfur content of .019 per cent. The only treatment that showed a marked effect upon the yield was Treble Superphosphate. For all treatments, the crop had a higher percentage of sulfur than the check. Sulfur, gypsum, and sulfur with lime caused the greatest increases. In this series the heavier applications of sulfur resulted in higher percentages in the crop. No striking differences are noted in the effect of the treatments on the nitrogen content of the crop, except in the case of the Treble Superphosphate which resulted in an increase in nitrogen content and in the total amount of nitrogen removed by the crop.

Palouse silt loam. The Palouse silt loam had the greater sulfur content of the soils studied, viz., .023 per cent. In this series, additions of lime alone, lime and sulfur, sulfur, and gypsum all caused marked increases in yield. The greatest increase was due to one ton of lime and 100 pounds of sulfur. One hundred and five hundred pounds of sulfur gave very nearly the same results. This indicates that the application of 100 pounds of sulfur per acre is sufficient for the Palouse silt loam. Indications are that lime alone benefits alfalfa on this soil but the best yields are produced when both lime and sulfur are applied. Raw rock phosphate and Treble Superphosphate both depressed yields slightly showing that phosphates are not necessary for alfalfa on this soil.

All forms of sulfur produced a marked effect on the sulfur content of the crops. Here again the larger addition of sulfur did not materially increase the percentage of sulfur in the crop but did decrease the yield slightly in comparison with the smaller application.

No uniformity exists in the data on nitrogen content since only the lime and sulfur additions caused increases. All treatments, with the exception of the phosphates, increased the total nitrogen removed by the crop. Lime and sulfur caused the largest removal and 100 pounds of sulfur and gypsum respectively less. Five hundred pounds of sulfur produced the same result as gypsum. Phosphates show a depressing effect on the total nitrogen removed by the crops.

When the relationship of the sulfur content of the soil is compared to the sulfur content of the alfalfa grown on the soils without treatments, it is seen that the soil richest in sulfur does not produce alfalfa with the highest percentage of sulfur. The two non-treated soils producing the highest percentage of sulfur in the alfalfa are the Aberdeen soil and Boise silt loam. Both are arid soils from southern Idaho requiring irrigation before crops can be grown. Both soils contain less sulfur than the Palouse silt loam. It is thought that the Palouse silt loam, while containing the highest percentage of total sulfur, does not contain as much of the sulfur in an available form for the

plant, but rather contains a high percentage in combination with organic matter and unavailable until decomposition and oxidation take place.

Moscow loam and Helmer silt loam contain practically the same amount of sulfur and produce alfalfa with equal sulfur contents. Both soils respond to sulfur treatments in producing increased yields of alfalfa, increased percentages of sulfur in the alfalfa, and increased percentages of nitrogen. In fact the only soil which does not respond with an increase in nitrogen in the alfalfa when sulfur is applied is the Boise silt loam. All other soils show marked increases in the nitrogen content of the crop when some form of sulfur is applied. Both the southern Idaho soils, (the arid soils) appear to have sufficient sulfur for normal plant growth. It is thought that where additions of sulfur cause a slight increase in yield on these soils that there is some effect other than that of supplying the sulfur needed as a plant food. On the humid soils of northern Idaho there is not only a marked increase in yield, but a like increase in the sulfur and nitrogen content of the alfalfa grown thereon, indicating that low yields secured on the check soils are due to an actual lack of available sulfur.

THE EFFECT OF LIME, LIME AND SULFUR, GYPSUM AND SULFUR ALONE, ON THE AMOUNT OF WATER SOLUBLE POTASSIUM IN THE DIFFERENT SOILS

The general opinion expressed by many text books that additions of lime and gypsum to soils results in a greater amount of available potassium and other elements in the water extract has been disputed to a considerable degree in late years.   These experiments were carried out to show the effect of lime, lime and sulfur, sulfur, and gypsum on the total potassium found in a water extract obtained under definite conditions for each soil.   For this purpose soil was used from the control pots of the experiments just reported which had stood for more than a year in a fallowed condition.   Only the potassium was considered, since this element usually showed the largest fluctuation in the water extracts from soils studied by other investigators.

Two thousand grams of soil was made up to a definite moisture content, allowed to stand twenty-four hours and then packed into a percolator. The amount of water added differed for each soil type but was the same for all treatments of the same soil.   Definite amounts of distilled water were added to each soil and after the first drop of percolate appeared, the percolator was closed, for 24 hours, then opened and the first 500 centimeters collected.   This was evaporated to a small volume and the potassium determined gravimetrically.   The results are comparative only within a given soil series.   The authors wish to state that this method is intended only to show relative differences and the results should be interpreted as such.   No comparisons should be made except within the same soil types.   The method was chosen because of difficulty encountered in securing uniform results on small amounts of potassium when the colorimetric method of Cameron and Failyer (4) was used.   Data are given in table 3.

An inspection of table 3 shows no uniformity in the effects of the treatments on the water soluble potassium.   Varying effects are noted with the same treatments on different soils.   While the results are only relative, they indicate that statements frequently found in text books on the effect of calciuum sulfate and calcium carbonate on the solubility of potassium in the water extract of soils are altogether too general.   Our results indicate that the effects may vary with different soils, which is only to be expected when the wide differences in composition of all soils is considered.

TABLE 3

Soluble potash in soils

TREATMENT	MOSCOW LOAM	HELMER SILT LOAM	SANDPOINT SOIL	ABERDEEN SOIL	BOISE SILT LOAM	PALOUSE SILT LOAM
	gm.	gm.	gm.	gm.	gm.	gm.
None..........................	0.0086	0.0109	0.0077	0.0422	0.0186	0.0120
Lime...........................	......	0.0112	0.0050	0.0527	0.0147	0.0095
Lime and sulfur................	......	0.0080	0.0068	0.0416	0.0152	0.0131
Sulfur........................	0.0115	0.0113	......	0.0450	0.0146	0.0151
Gypsum.......................	0.0107	0.0075	0.0101	0.0500	0.0153	0.0150

SUMMARY

The effect of additions of lime, sulfur, gypsum and phosphorus on the yield of alfalfa, on the nitrogen and sulfur content of the crop, and on the soluble potash in the water extract of the soil was studied on six Idaho soils.

Four of these soils are from the humid portion of the state and two from the arid portion.

Sulfur in some form produced a distinct increase in the yield of alfalfa grown on the soils from the non-irrigated part of the state.   The application of sulfur to the arid soils produced no marked effect upon the yield of alfalfa.

Sulfur in all forms produced an increase in the total nitrogen removed by the alfalfa.   All applications of sulfur increased the percentage of sulfur in the plant.

Different forms of sulfur produced varied effects for each soil on the yield and composition of the crop.   Phosphorous increased the yield of alfalfa on all but two of the soils.   The arid soils give a greater response to applications of phosphorous and less to sulfur than humid soils.   All applications of phosphorous increased the percentage of sulfur in the alfalfa and produced slight increases in the nitrogen content of the alfalfa in all but two of these soils.

The effect of these treatments on the soluble potash is variable, depending upon the soil type.

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